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Water and energy self-supply in isolated areas through renewable energies using hydrogen and water as a double storage system

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A B S T R A C T

Because of their geographical isolation, many areas depend mainly on imported fossil fuels for their water and energy production. In this context, the Canary Islands are one such remote area. Due to the topography of the islands, there are numerous isolated areas on each of the islands far from the major population centres. These are known as 'islands within islands'. The main aim of this paper is to determine the feasibility or otherwise of supplying from renewable energy sources both the energy and water needs of the 219 inhabitants of El Risco located in the municipality of Agaete on the island of Gran Canaria (Spain). For this purpose, the potential use of existing renewable resources in this isolated area has been analysed, using hydrogen as energy vector. A reverse osmosis (RO) plant is integrated into the system to ensure water self-sufficiency and, in turn, constitutes a double storage system (hydrogen-water). Based on the results obtained from the study, the technical feasibility of the system is confirmed, with an annual energy production of 1,743,031 kWh/year compared to a consumption of 672,314.32 kWh/year, as well as a potable water production volume of 46,546.80 m^3/year obtained from the RO plant. The reliability of the system is confirmed in the economic analysis, obtaining a renewable electricity cost of 0.107 €/kWh compared to 0.18 €/kWh when using conventional electricity.

1. Introduction

It is widely recognised that the current energy system is unsustainable given the finite nature of the fossil fuels which form its basis. The fact that humanity consumes in just a single year the same amount that nature required a million years to create should be sufficient to make clear the rapidity at which fuel reserves are being exhausted [1].

Not only are these fuels an important contributing factor to the greenhouse effect and acid rain, but they also drive deforestation and are the cause of social tensions and even wars between countries who endeavour to ensure their energy supply while having to contend with continued fluctuations in the price of oil [2].

This problem is aggravated in geographic regions which are characterised by their dependence on external-sourced energy. Many of these regions, principally but not exclusively islands, can be considered isolated areas as they depend completely on the import of fossil fuels for energy production [3].

The outermost regions of the European Union, one of which is the Canary Archipelago (Spain), are a clear example of the type of situation considered in the present study. In our particular case, the topography of Gran Canaria island is highly complex and diverse as the result of its geological formation, its subsequent evolution and its climatological characteristics. In consequence, there are numerous small, semi-remote villages - whose inhabitants work principally in agriculture, cattle-farming or rural tourism - located at some distance from the main sources of water and energy (which, in the case of energy, is mostly imported from mainland Spain).

Such remote areas on Gran Canaria include, amongst many others, El Risco, Casas de Veneguera, El Horno, Fagajesto, Chira, La Culata, Artejevez, Ayacata, Artenara and Trejo [4]. These have been described as 'islands within islands' (geographically isolated areas in a geographically isolated archipelago). This new concept arises from the weaknesses which on occasions manifest themselves in the energy transmission line when anomalous situations occur that generate considerably higher energy demand (whether due to tourism, industry or seasonal fluctuations). These villages are therefore clear examples of situations which could benefit from the implementation of distributed generation or microgrid systems.

Presently, a series of different approaches are being investigated in an attempt to reduce the worldwide dependence on fossil fuels. One of these approaches involves the use of renewable energy sources, creating scenarios that are environmentally clean and respectful and that consequently avoid the emission of huge amounts of contaminating gases

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[5].

Systems such as those described in studies by Mehdi Baneshi et al. [6], Golbarg Rohani et al. [7], Barun K. Das et al. [8] and Normazlina Mat Isa et al. [9] employ renewable energies stored in batteries and supercapacitors. Other renewable systems, as is the case of Bahram et al. [10], Sihem Nasri et al. [11] and Nicu Bizon et al. [12] avoid conventional storage methods and instead use hydrogen as energy vector, using it as a means of storage to again produce electricity with fuel cells. Systems can also be found with a symbiosis between these two storage types, as is the case of Anand Singh et al. [13].

All these cases, and particularly those which store hydrogen, have resulted in major improvements and a high degree of self-sufficiency. However, the aim of the present work is not only to supply the energy demand with renewable-sourced energies, but also to guarantee at the same time self-sufficiency in terms of meeting the water demands of the population. For this latter purpose, a reverse osmosis (RO) plant has been included in the proposed system. As such, the innovation of the proposed system lies in its use of both water and hydrogen as a double energy storage system.

With all of the above in mind, the present study analyses the technical feasibility of a distributed generation system which uses wind and solar technologies in a remote region on the island of Gran Canaria (Spain), called “El Risco” (see Fig. 1).

The main basis of this feasibility analysis is undertaken with the “Hybrid Optimization of Multiple Energy Resources” (HOMER) microgrid modelling software [14]. In addition, a simulation is undertaken in parallel of the RO plant using the Reverse Osmosis System Analysis (ROSA) design software [15]. In this way, both types of demand (energy and water) are covered and a double storage system employed (hydrogen and water). The above is explained in greater detail in sections 3 and 4 of the present paper.

‘El Risco’ is considered a remote area in view of its infrastructure and economy, as well as its location. This area has been chosen as it is one of the furthermost regions on the island from the capital city of Las Palmas de Gran Canaria (47.3 km). Compared to other isolated regions on the island its population is relatively high, and its climatic conditions (low rainfall, high percentage of sunny days and exploitable wind conditions) [16] and location (at ground level of a ravine) mean that the proposed system could be installed nearby to take advantage of the excellent wind conditions in the surrounding area, making it an optimal area for implementation of the system.

At the present time, the energy demanded by El Risco is supplied conventionally by the island grid from the Juan Grande plant, located some 92 km away, where more than 80% of the energy is generated from fossil fuels. The water demand is met through the desalination plant in Gáldar, 25.8 km away.

The variation in electricity demand over the course of a day for the population of El Risco shows maximum consumption levels during the middle hours of the day and the early hours of the evening. Fig. 2 shows a comparison of the different power peaks and troughs over a 24-hour period on the fifteenth day of three different months in 2014.

The annual load curve, with the maximum powers recorded in each month, is shown in Fig. 3. Both Figs. 2 and 3 were generated using values obtained from the database of Red Eléctrica de España, Spain's electricity system operator.

2. Description of the system

The proposed system comprises both wind and photovoltaic renewable energy technologies, and is completed with an electrolyser, a fuel cell and a hydrogen storage tank. In addition, an RO plant has been included to supply water to the local population.

The aim is to ensure the supply of the 672,314.32 kWh/year consumed by the 219 inhabitants of the area as well as to meet the water demand of 15,987 m^3/year, using renewable-sourced energies and employing a double storage system (hydrogen and water). By these means, the yearly emission into the atmosphere of some 664,010.18 kg/CO_2 could be avoided, a total of 49,078.93 €/year could be saved in terms of electricity (production and transport costs), as well as 10,071 €/year with respect to meeting water demand.

Schematically, the system has the configuration described in Fig. 4.

2.1. Operating modes

The operating modes that describe the system are essentially as follows [17], and are shown in Table 1:

- The system consists of an electrical energy generation plant using wind and solar irradiation as prime energy resources. During periods of high electricity demand, the energy that is produced is fed into a stand-alone grid to supply the energy needs of the population of El Risco.
- During low demand periods, the plant will use the surplus energy generated to produce hydrogen by means of water electrolysers. In addition to hydrogen production, when enough excess energy exists the system will also produce potable water in an RO desalination plant.
- The hydrogen will be stored and fuel cells (FC) will be used to produce electrical energy when the wind and solar conditions are insufficient to directly meet the energy demand of the population [3,18,19,and 20].

The primary purpose of the system is to meet the energy needs of the population. However, if the system is also capable of satisfying potable water requirements, the population can be become practically self-sufficient. Bearing in mind the climatic conditions of the Canary Islands, the available renewable resources (mainly wind) fluctuate considerably and so, ex ante, it is assumed that even the most optimized system will have a significant surplus of energy. This excess energy could be used for water desalination, either seawater extracted from the

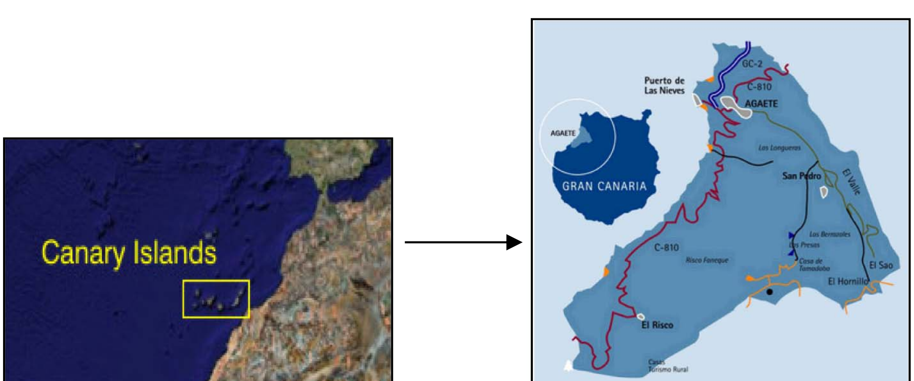

Fig. 1. Map of Canary Islands, Gran Canaria and ‘El Risco’.

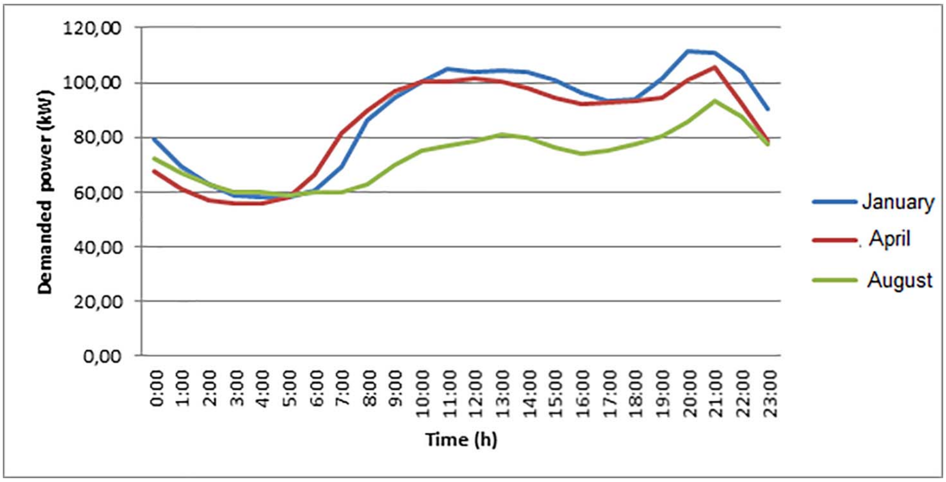

Fig. 2. Time load curve for the days of the specified months.

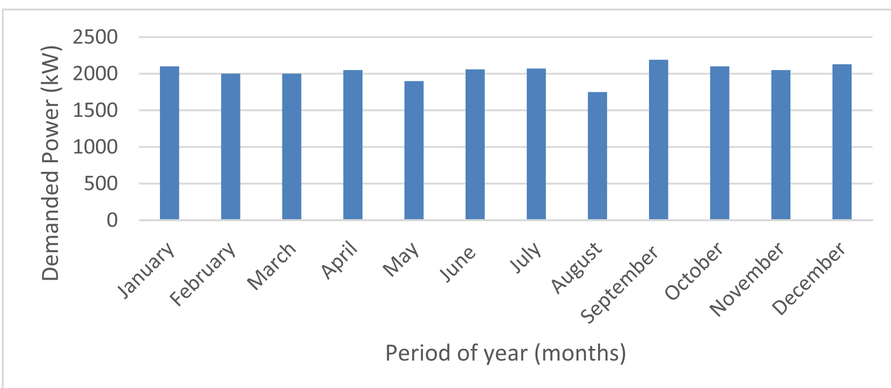

Fig. 3. Monthly energy consumption of the population of "El Risco".

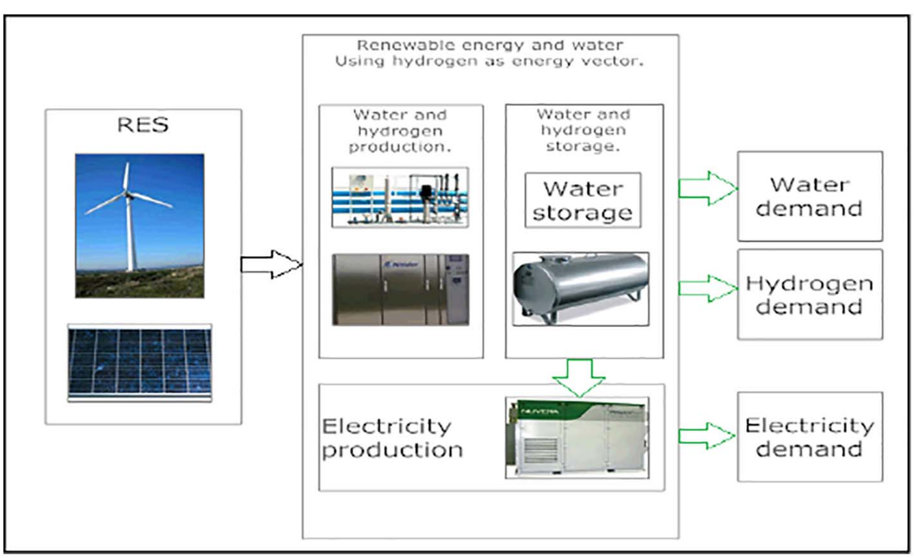

Fig. 4. Schematic description of the system.

coast of 'El Risco', or from a nearby well (brine or otherwise).

The operation of the integrated system involves a number of decisions regarding the management and use of power. The operating strategy is shown in Fig. 5.

The following flowcharts are included to better explain the five possible scenarios. The components of the system which are in operation are marked with an 'X' below each flowchart.

Scenario 1. Renewable energy has the same value as power demanded (Fig. 6).

Scenario 2. Renewable energy has a higher value than the sum of the energy demand and the minimum working powers of the electrolyser and the RO plant (Fig. 7).

Scenario 3. Renewable energy has a value higher than the sum of the energy demand and the minimum working power of the electrolyser but does not reach the power required for the RO plant to operate

Table 1
Operating system modes.

	Demand	Electrolyser	H_2	Fuel cell	H_2O
Load + P_{ELZnom} < RE ≤ Load + P_{ELZnom} + RO_{nom}	RE	+	↑		↑
Load + P_{ELZmin} < RE ≤ Load + P_{ELZnom}	RE	+	↑		
Load ≤ RE ≤ Load + P_{ELZmin}	RE		=		↑
0 < RE < Load	RE + FC		↓	+	
0	RE		↓	+	

Where: RE: Renewable Energy; FC: Fuel Cell; RO_{nom}: Reverse Osmosis Rated Power; P_{ELZnom}: Electrolyser Rated Power; P_{ELZmin}: Electrolyser Minimum Power.

(Fig. 8).

Scenario 4. Renewable energy has a higher value than the energy demand but does not reach the power required for the electrolyser to operate (Fig. 9).

Scenario 5. There are no renewable energies (Fig. 10).

3. Simulation

The population of 'El Risco' could attain complete autonomy and independence in terms of its water and energy requirements. The aim is to lower the high costs of water production by meeting the demand with renewable energy sources. If excess energy is not used for this purpose, it would in principle be wasted.

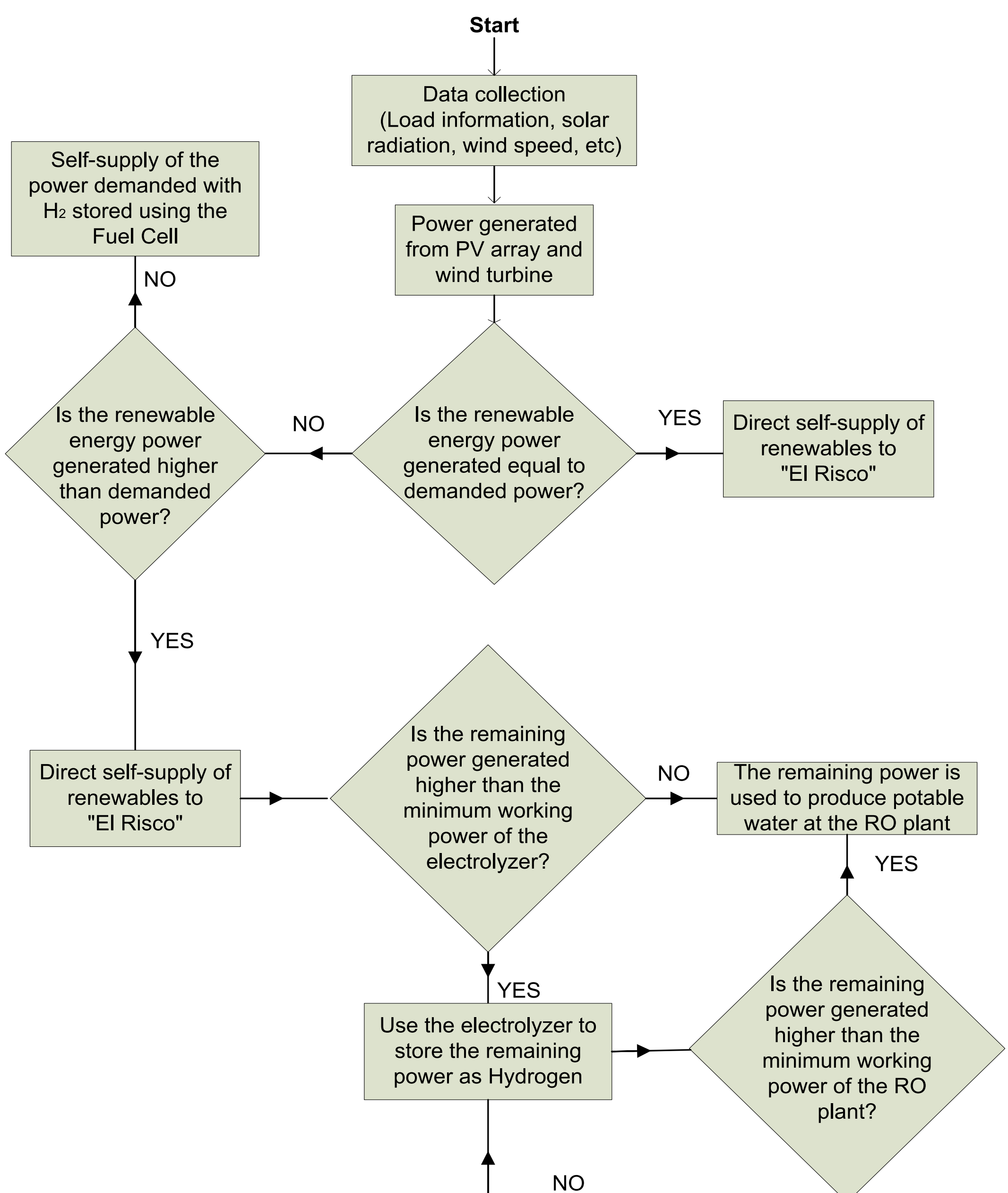

Fig. 5. Logical block diagram.

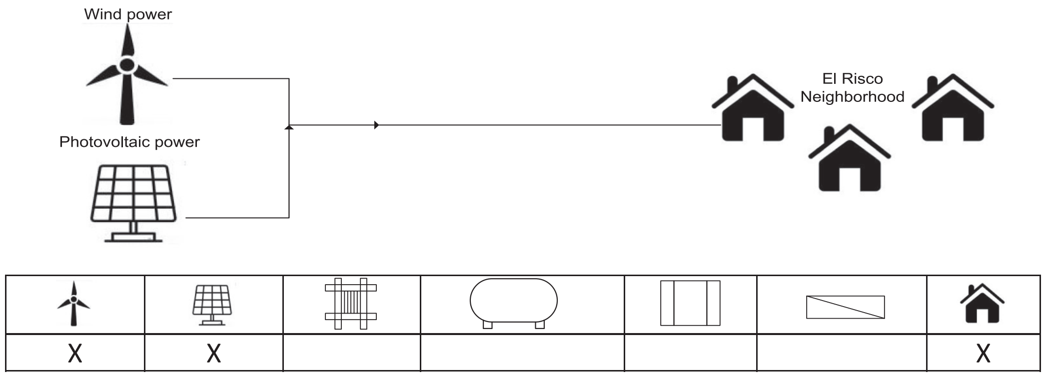

Fig. 6. Scenario 1 flowchart.

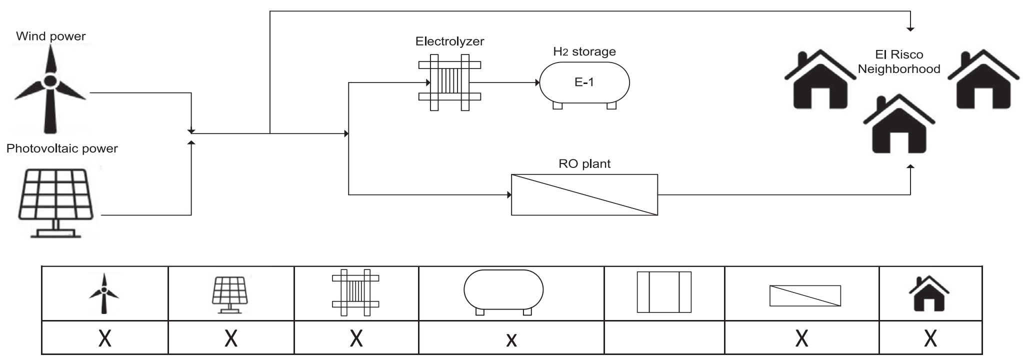

Fig. 7. Scenario 2 flowchart.

3.1. Homer assumptions

One of the programs used to carry out the simulation was developed by the National Renewable Energy Laboratory (NREL) [14]. HOMER, known as Hybrid Optimization Model for Electric Renewable is a computer simulation program that allows the design for grid (non-autonomous) and non-grid (standalone) connected power systems comprising conventional and renewable energy systems. The simulation software has the capability of carrying out economic and technical feasibility studies of power systems and shows results covering the net present capital cost of the system for effective renewable energy penetration [21]. It also performs sensitivity analyses to evaluate the impact of a change in one or more of the input parameters [22].

HOMER evaluates different energy options by simulating hourly energy flows and making energy balance calculations for each of the 8760 h of the year. After simulating the system configurations, the model displays a list of feasible systems, sorted by lifecycle cost based on their net present values (NPVs). Then, based on the results, it is possible to choose from amongst the least costly feasible systems [23].

For a particular application scenario, inputs to HOMER include load data, renewable resource data, system component specifications, costs and various information of optimization (e.g. number of components) [24]. It was decided to use this tool as it allows a comparison between DC (direct current) and AC (alternating current) coupling systems. HOMER is also highly flexible in simulations and allows adjustment of the program to suit different requirements [20].

3.2. Homer model description

The specific system design is shown below (Fig. 11):

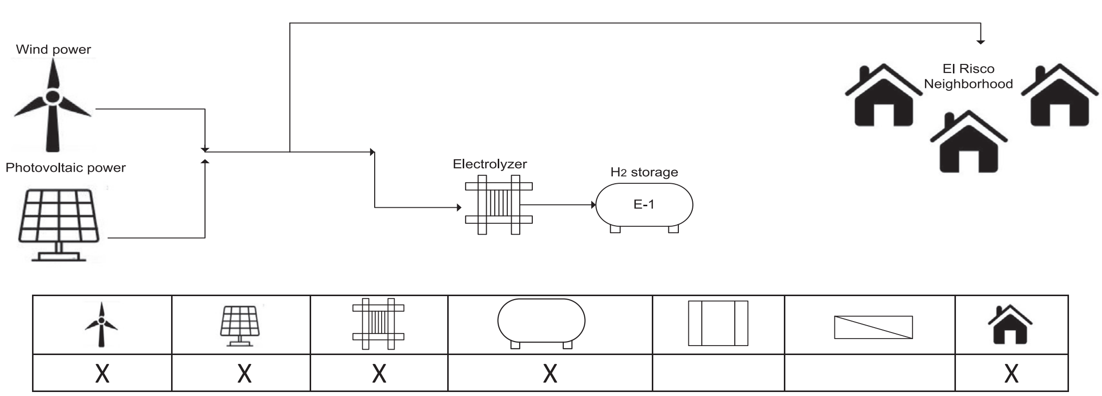

Fig. 8. Scenario 3 flowchart.

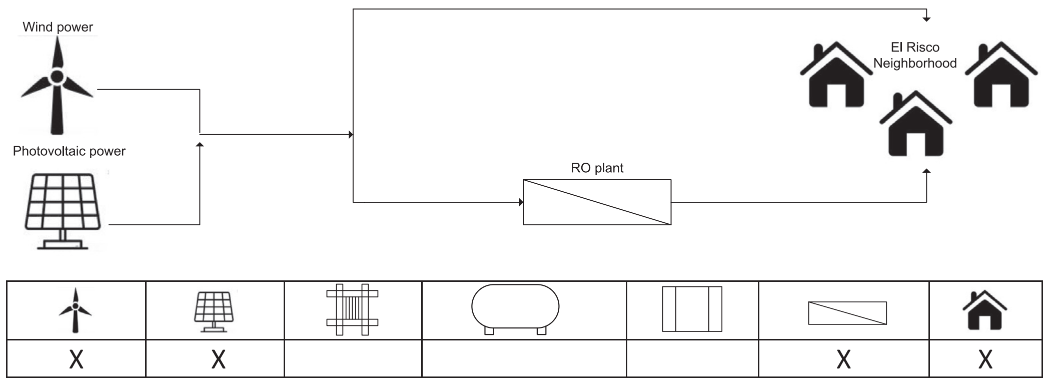

Fig. 9. Scenario 4 flowchart.

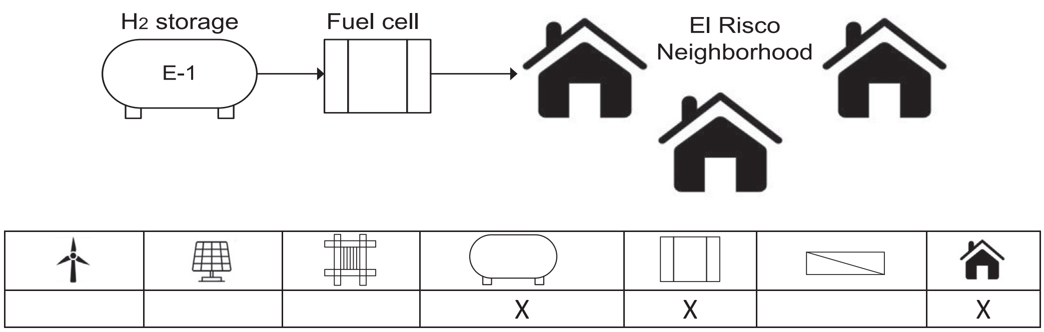

Fig. 10. Scenario 5 flowchart.

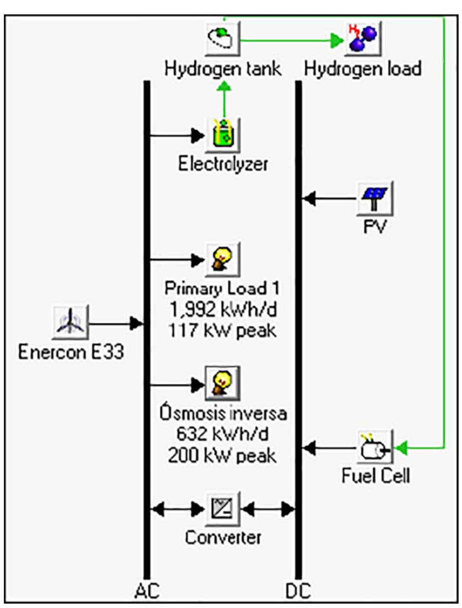

Fig. 11. System simulation.

Both primary load and water consumption data were obtained by extrapolating real data of water and energy consumption on Gran Canaria Island. The principal data of the system obtained are shown below (Fig. 12):

The COE (cost of electricity) obtained with this system of 0.107 €/kWh is competitive with other rates [25,26]. Although the main aim is to meet energy demand, to do so this was sized based on the power peak of the energy curve. As one of the innovations of the present study, it was decided to use this surplus energy (unlike other case studies in which it is stored in conventional batteries) for the production of potable water with the incorporation of an RO desalination plant. The surplus energy obtained in the system, which it is intended to use to obtain water through RO, amounted to 232,734 kWh. Given that approximately 5 kWh are required to obtain 1 m^3 of desalinated water, this excess amount of energy could be used to produce a total of 46,546.80 m^3/year. Since this amount is considerably higher than the minimum requirements of the population (15,987 m^3/year), the excess water could be purchased by local farmers or used to create a water reserve. Due to seasonal fluctuations in the renewable energy resources, the amount of water that can be produced with the excess energy will vary from month to month. Table 2 shows the excess kWh per day and the corresponding m^3/day of potable water that can be produced for each month of the year.

As can be seen in the second table, July is the month with the highest potential for water production (335 m^3/day on average). The installed production capacity of 3·115 m^3/day of the RO equipment means that the system can meet this level of production.

The specific simulation with respect to RO is shown in Fig. 13. Homer has the option to include a secondary load which is satisfied only when the primary load is satisfied. With the aim of adjusting to the maximum extent the surplus energy to the load for the RO plant, all the surplus energy data were extracted for one year and used to construct the expected demand curve for the desalination module, leaving a small margin for possible fluctuations in supply and demand which may take place over the useful lifetime of the system.

3.3. Rosa assumptions

The RO process was simulated with ROSA (Reverse Osmosis System Analysis created by Dow Chemical). This industry-leading RO system design tool makes it easy to design an RO plant to meet the required water treatment specifications [15].

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

	PV (kW)	E33	FC (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	COH ($/kg)	Ren. Frac.	Capacity Shortage	FC (hrs)
	150	1	100	130	175	500	$ 845,891	30,705	$ 1,238,400	0.107	9.114	1.00	0.08	4,863

Fig. 12. Optimization results.

Table 2
Excess kWh/day and the corresponding potable water/day that could be produced each month.

Average	kWh/day	m^3/day
January	249	50
February	387	77
March	780	156
April	588	118
May	360	72
June	854	171
July	1674	335
August	1188	238
September	714	143
October	314	63
November	338	68
December	202	40

Introducing the concentration of ions in the feedwater and selecting the required type of FILMTEC™ element, ROSA performs the complex mathematical computations that are needed, trying different configurations and generating a full but simple-to-understand report which predicts water quality [27,28] and flowrate. The best possible performance for the system was determined to be 2 pressure vessels in parallel with 6 membranes per pass.

3.4. Rosa model description

The ROSA-optimized RO planta comprises two stages/passes; a first stage with two pressure vessels of six SW30ULE-440i DOW energy membranes [29] (chosen as they are low energy membranes), and a second stage comprised of a six membrane pressure vessel of the same model. The data for the different feedwater, permeate and reject characteristics are shown in Table 3 and the flowchart taken from the ROSA simulation program is shown in Fig. 14.

As mentioned, the system has 2 stages/passes; the second, with a membrane located in series, is fed by the permeate from stage 1. ROSA was designed to work with fixed permeate flowrate data, whereas the proposed system will have variable flow depending on the availability of surplus energy. For this reason, the simulation was performed with total permeate capacity to find the maximum system flowrates and pressures.

As total dissolved solids (TDS) permitted by law (potable water supply) are between 0 and 5 mg/l, the system meets this specification (see Table 3) [30].

3.5. Energy production

The energy production and consumption values of the different elements of the system are shown in Table 4. When primary load has

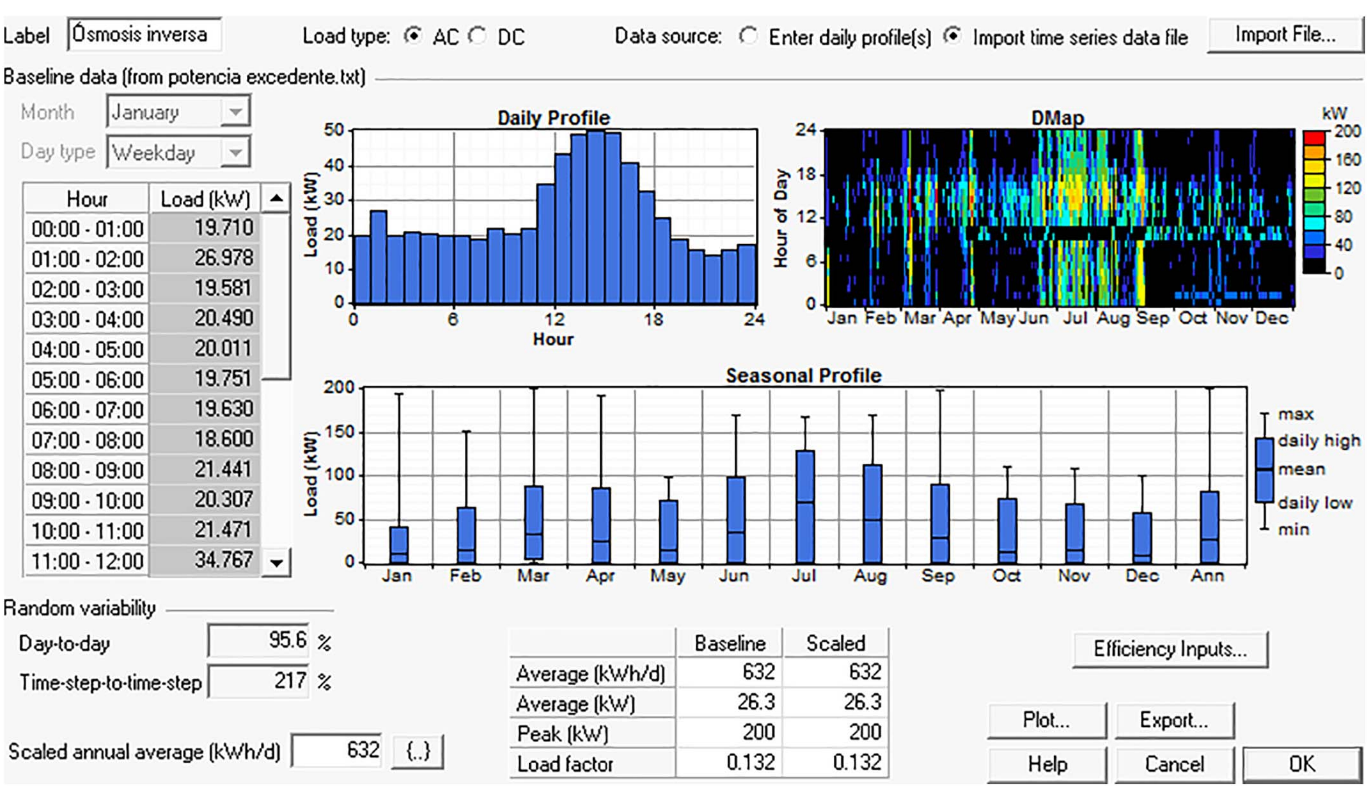

Fig. 13. Characteristics of the RO energy load.

Table 3
Data obtained from ROSA software.

Stage 1				Stage 2			
Stream	Flow (m^3/day)	Pressure (bar)	TDS (mg/l)	Stream	Flow (m^3/day)	Pressure (bar)	TDS (mg/l)
1	567.91	0.00	37,120.97	1A	255.56	–	89.94
3	567.91	71.80	37,122.24	3A	255.56	137.90	89.94
5	312.56	69.81	67,420.03	5A	165.03	137.43	138.24
7	255.56	–	89.94	7A	90.54	–	2.00
7/1	Capacity	45%		7A/1A	Capacity	35.43%	

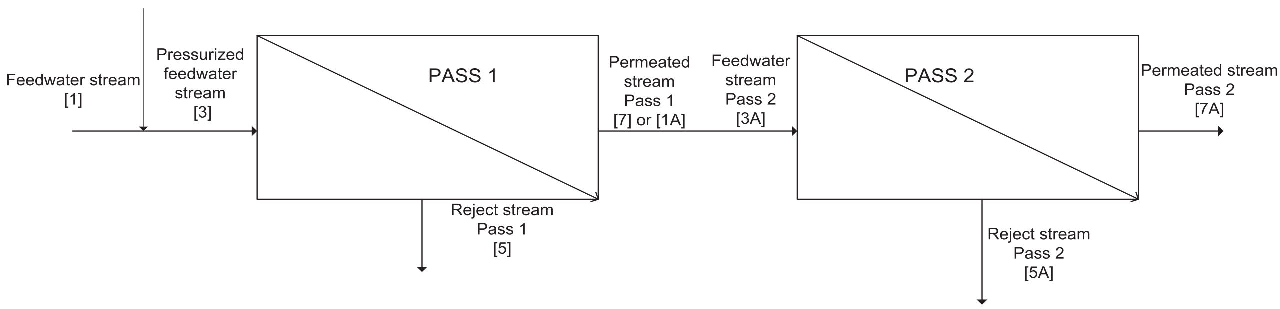

Fig. 14. Reverse Osmosis simulation.

Table 4
Characteristics of the energy system.

	Rated power (kW)	Energy (kWh/year)	Percentage (%)
Produced energy			
PV	150	284,194	16
Enercon E33	330	1,312,836	76
Fuel cell	100	128,214	7
Total		1,725,244	100
Consumed energy			
Primary load AC	130	674,666	46
Reverse Osmosis load	26.3	230,590	16
Electrolyser	175	558,998	38
Total		1,464,254	100
Other amounts			
Excess energy		230,703	13
Unsatisfied energy load		52,442	5.5
Capacity shortage		73,737	7.8

been satisfied any surplus energy can be used for the electrolyser and to operate the RO plant.

Fig. 15 shows monthly electricity production, with most production provided by the wind turbine. A notable difference can be seen between the summer months and the rest of the year. This is due to the presence of the trade winds which are typical of the geographic region of the Canary Archipelago (Macaronesia).

3.6. Hydrogen storage

According to the simulation data, the tank would contain just 48 kg which would mean the need to purchase 452 kg in order to fill the 500 kg capacity tank. The following solution is proposed for this problem. A hydrogen load can be added in the last month of the year by making the electrolyser work harder in periods in which there is surplus energy. In this way, the amount of hydrogen required to finish the year with a full tank can be achieved.

To ensure hydrogen production without the system being affected, this should only be undertaken in periods in which the system cannot accept the amount of renewable energy generated by the system. As the aim of this tool is to obtain hydrogen as energy vector so that at the end of the year the tank is as full as possible, the simulation of hydrogen production was carried out by attempting to have all the surplus energy, in the last month of the year, used to obtain water instead of hydrogen, thus storing the energy in the form of water. In this way, the supply of hydrogen and water is ensured at year's end. Fig. 16 explains the simulation and behaviour of the volume of stored hydrogen.

It would have been possible to indicate to HOMER that a full tank at

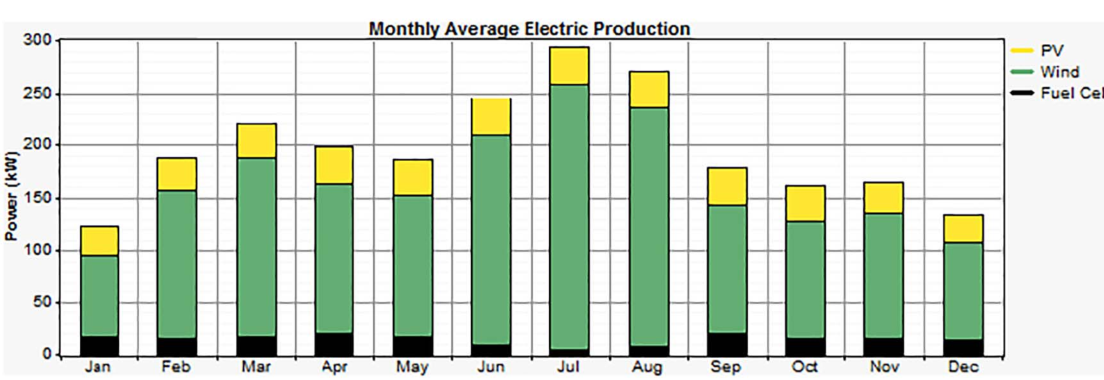

Fig. 15. Monthly electricity production.

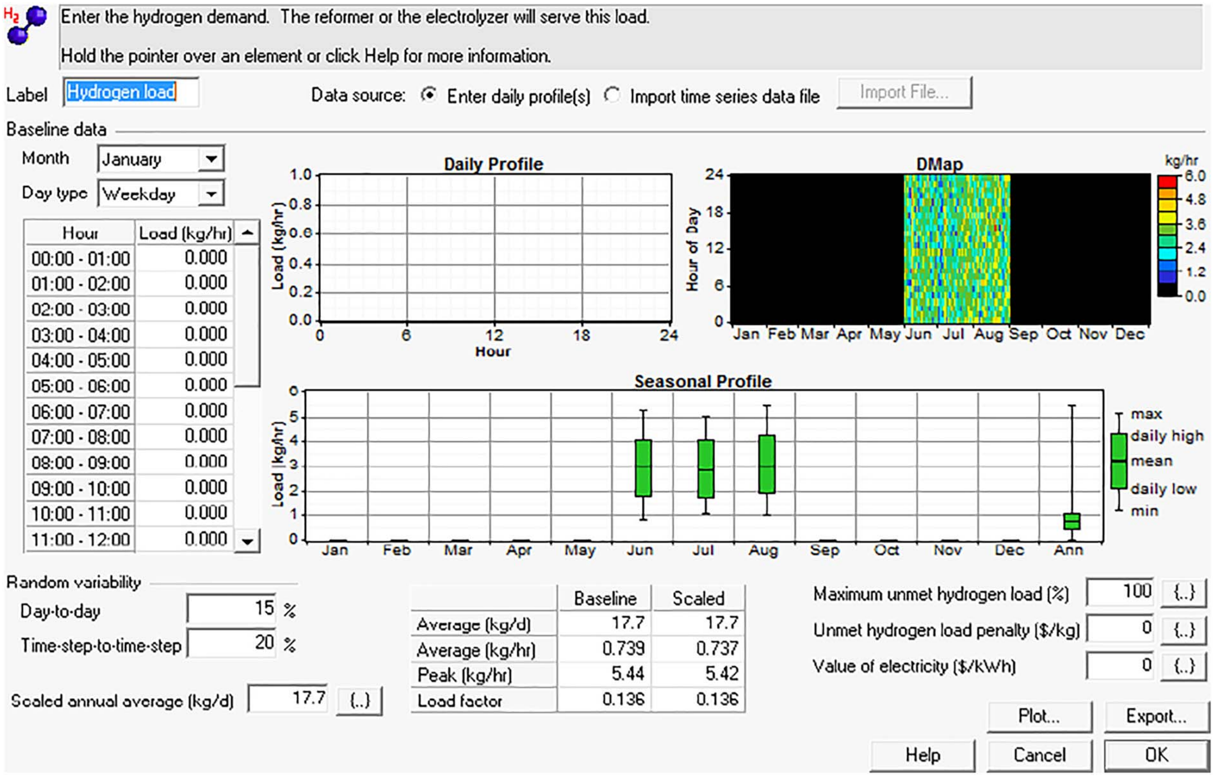

Fig. 16. Hydrogen simulation.

year end was a prior condition of the system, but HOMER (see Fig. 17) designs systems to satisfy the load at times when wind and solar energy output are minimal. Imposing the condition that the tank had to be full at year end would have entailed significant oversizing of the system. The total production of hydrogen was 10,628 kg/year. The production cost per kg of hydrogen was 8.48 €.

If the system obtained is compared with the employment of a diesel generator set (typically used in solutions for the supply of water and energy to remote areas), it can be seen how, in order to meet an average daily demand of 76.75 kW, some 19.21 kg/h of diesel fuel would be required [31], while some 28 kg/h would be needed to meet peak demand. If we bear in mind that fuel production in the Canary Archipelago has an associated cost of 490.40 € per metric ton [32], it is confirmed that the designed system operates within a highly competitive range of values (0.107 €/kWh renewable energy system vs. 0.12 €/kWh diesel-generator set).

4. Data analysis

The basic modes of control and operation in HOMER using data obtained from the optimum scenario are discussed below. The performance of the system during periods of deficit and surplus energy is analysed in the following figures by using the energy balance of three particular days, more precisely April 15, August 15 and November 15 (studying the behaviour of the wind and solar resource and energy demand). It was decided to work with these days to try to cover the different seasons and climate changes that could take place throughout the year.

This serves as a tangible example of the huge fluctuation in the energy output of the renewable resources available on the island, demonstrating the importance of storage in such systems.

The three basic modes are explained in detail below:

- The main purpose of the system is to cover the required energy requirements of the population directly through energy generated

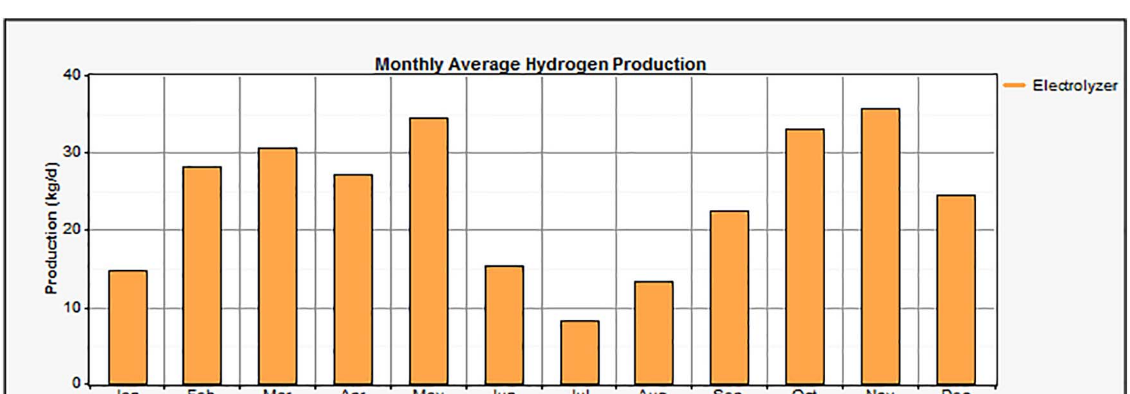

Fig. 17. Monthly average hydrogen production.

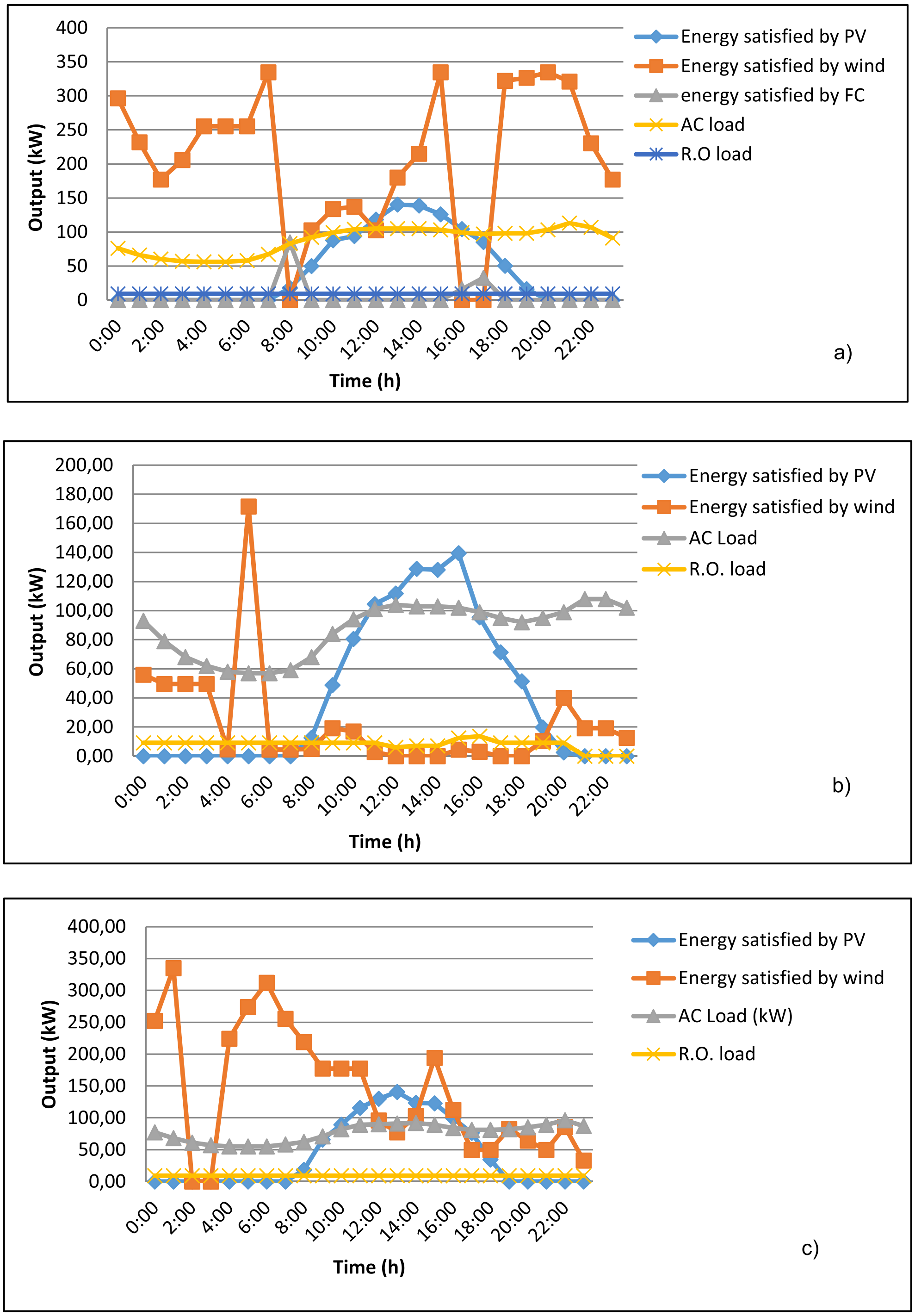

Fig. 18. a), b) and c). Energy supply with renewable energy.

from renewable sources.

- In periods in which the wind turbine and photovoltaic panels produce more energy than is required to satisfy the energy needs of the local population, this surplus energy is sent initially by the system to the electrolyser, storing the hydrogen as gas, and, if sufficient energy remains available, subsequently to the RO system.
- Conversely, in time periods in which there is a shortfall in electricity generation, the fuel cell is put into operation, using the stored hydrogen as fuel and thereby meeting the energy requirements of the local population.

For Figs. 18, 19 and 20: a) corresponds to data for April 15, b) to data for August 15 and c) to data for November 15.

In Fig. 18a), b) and c), the power demand and renewable energy resource curves are shown. While solar potential follows a curve that increases and decreases according to daylight hours, wind potential fluctuates considerably with major peaks of energy acquirement in certain time periods.

Fig. 19a) b) and c) shows system operation when there is a surplus of energy due to the start-up of the electrolyser. The shape of the curve of the electrolyser for the three days can be seen to be very similar to that of the wind turbine. This is because, if demand can be supplied with solar energy, a large part of the wind energy can be used to generate hydrogen. For example, on November 15, when large amounts of

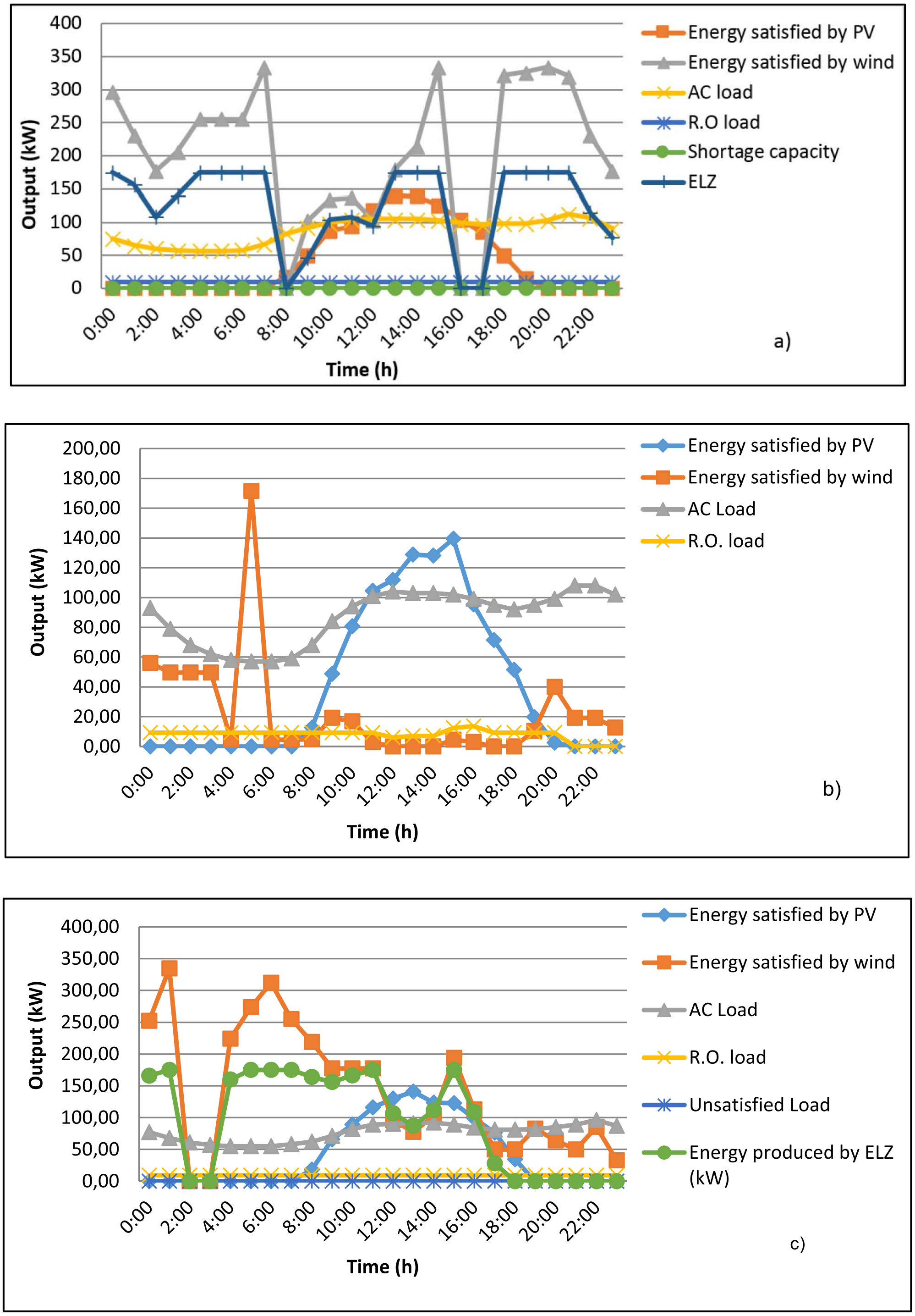

Fig. 19. a), b) and c). Operating the electrolyser in periods with excess energy.

wind power were generated, the shape of the curve of the electrolyser is practically the same at many moments over the course of the day.

Finally, Fig. 20 shows how the hydrogen fuel cell is activated during periods in which renewable power output is insufficient to cover all energy requirements. The fuel cell and the renewable energy resources are able to satisfy all the water and energy demand.

For example, on April 15, it can be seen how at dawn at 08:00 when no wind energy is being generated, the fuel cell is responsible for meeting the demand peak taking place at that moment.

5. Environmental study

The system described in the present paper to supply the energy and water requirements of an isolated population avoids the emission of harmful greenhouse gases (GHGs) into the atmosphere [33,34].

The GHGs avoided, when considering the CO_2 emission factor and the primary-to-final energy conversion factors for the Canary Archipelago, confirm the environmental benefits [35]. It is important to take into consideration the geographical area as the factors differ accordingly. The values for mainland Spain, the Balearic Islands and the Canary Islands are all different (Tables 5 and 6).

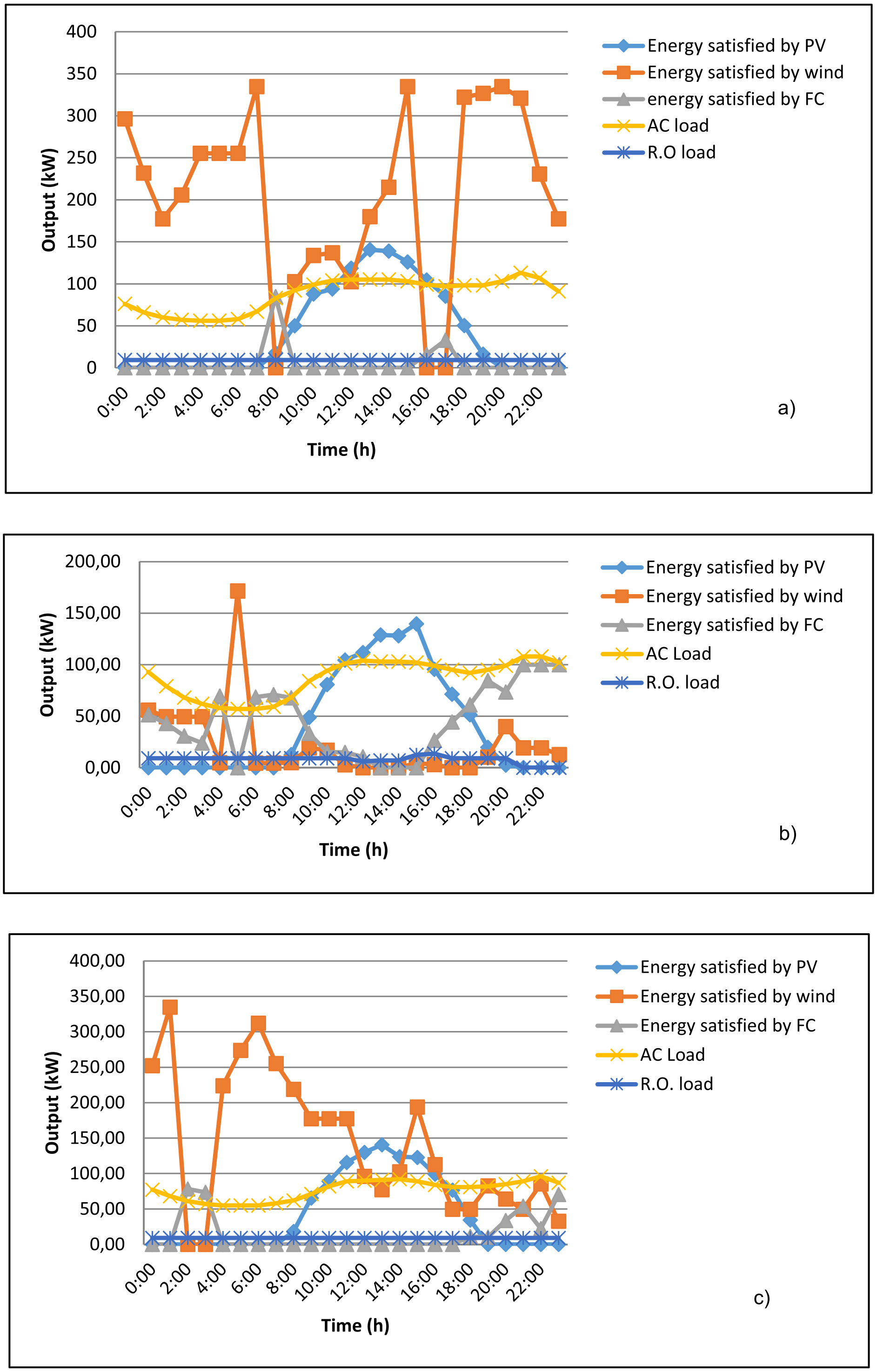

Fig. 20. a), b) and c). Operation of the electrolyser in periods with deficit energy.

The amount of kWh consumed by the population of 'El Risco' over a year is estimated at 674,655 kWh. At the present time, the energy used in 'El Risco' is obtained conventionally, so the primary kWh of energy needed to supply the energy needs of the local population can be calculated as follows [36]:

$$C_{\text{Primary energy}}(\text{kWh}) = C_{\text{Final energy}}(\text{kWh})\cdot K_{\text{Primary energy}}$$
$$C_{\text{Primary energy}}(\text{kWh}) = 674,655\cdot 3.117 = 2,102,899.64\ \text{kWh}$$

where C is the amount of electricity consumed and K is the ratio to convert to primary energy.

The designed system emits no CO_2 gases into the atmosphere, thereby avoiding the emission of harmful GHGs. The amount of GHGs avoided annually is 547,145,205 kg of CO_2.

$$C_{CO_2} = C_{\text{Final energy}}\cdot K_{CO_2\ \text{emission}}$$

The emission of over 500 tons of carbon dioxide a year could therefore be avoided by installing the proposed renewable energy system with hydrogen and water storage in 'El Risco'.

Water consumption for the town was calculated at 15,987 m^3 per

Table 5
Conversion factors in the Canary Islands [35].

Primary to final energy conversion factors			
	kWh primary renewable energy/kWh final energy	kWh primary non-renewable energy/kWh final energy	kWh primary energy/kWh final energy
Canarias conventional electricity	0.059	3.058	3.117

Table 6
Emission factors in the Canary Islands [35].

CO_2 emission factors	
	kg CO_2/kWh final energy
Canarias conventional electricity	0.811

Table 7
Conversion and emission factors for water desalination in the Canary Islands.

Use of energy to obtain potable water		
	Energy intensity	Carbon footprint
Transport	0–3.70 kWh/m^3	0–3.00 kg CO_2/m^3
RO treatment	5 kWh/m^3	4.05 kg CO_2/m^3
Distribution	0.18–0.32 kWh/m^3	0.15–0.26 kg CO_2/m^3

Table 8
"El Risco" case study results.

"El Risco" case study			
	Water produced (m^3)	Carbon footprint	kg CO_2 avoided
Transport	15,987	3.00	47,961
Treatment	15,987	4.05	64,747.35
Distribution	15,987	0.26	4156.62

year. Currently, the production of this amount emits each year the following quantities of CO_2 into the atmosphere [35], considering the conversion and emission factors for water desalination in the Canary Islands (see Tables 7 and 8).

The method of obtaining potable water using the proposed system avoids the annual emission into the atmosphere of 116,864.97 kg of CO_2. The total saving in terms of GHG by supplying the water and energy needs of the population through the proposed system amounts to 664,010.18 kg.

Over 600 tons of CO_2 are discharged into the atmosphere each year for the sole purpose of supplying water and energy to a population of just over 200 inhabitants. This amount is equivalent to the emissions caused by 250 petrol cars in one year [37]. At the same time, to absorb this amount of carbon dioxide would require a total of 60,000 trees, which are distributed in a space of 371 acres [38,39].

If a diesel group system had been implemented as a solution to an isolated system, it would not have been possible to avoid those tons of CO_2 emitted into the atmosphere.

Table 9
Specific cost per component.

Component	Capital (€)	Replacement (€)	O&M (€)	Salvage (€)	Total (€)
PV	109,488	0	0	− 4252	105,236
Enercon E33	240,876	0	61,616	0	302,492
Fuel cell	182,482	232,223	3210	− 36,601	381,314
DC/AC converter	6477	2703	1662	− 503	10,339
Electrolyser	178,832	0	45,713	0	224,545
Hydrogen tank	127,737	0	13	0	127,750
RO	207,000	50,750	12,420	0	270,170
System	1,052,891	285,676	124,634	− 41,356	1,421,845

6. Economic analysis

After the system had been generated, it was seen that the initial cost amounts to 1,052,891 € and the net present cost (NPC) to 1,421,845 €. Fig. 21 shows a breakdown of the costs of each component that comprises the energy system.

The costs of the RO plant need to be added with respect to both the initial investment and the annual costs (operating, maintenance and replacement).

The cost of an RO plant (without economy of scale) is 600 €/m^3/day [40]; the installation of 3 modules of 115 m^3/day of permeate requires a capital cost of 207,000 €. Operating and maintenance costs are estimated at 6% of initial investment. The cost of replacement membranes, calculated based on different projects with similar flowrates, was estimated at 2030 € per year.

Table 9 offers a breakdown of the relative costs for each component of the system.

With a view to knowing the feasibility of the project, the net present value (NPV) was calculated. The positive value that was obtained (865.174, 14) confirms the success of the system model. Through a cashflow analysis to consolidate the economic study, it was confirmed that the break-even year of the project is year 10.

7. Conclusions

Most remote or semi-isolated areas, as is the case of islands, even

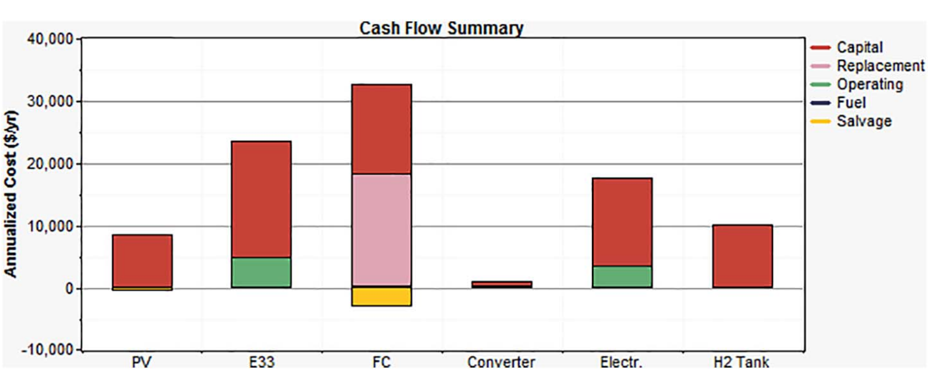

Fig. 21. Annual costs for the system.

when they have at their disposal their own energy resources (wind and solar energy, principally), tend to satisfy their energy and water requirements through the use of external fossil fuel-based resources.

The system proposed in the present study demonstrates the feasibility of using own resources (solar-wind) to replace non-renewable energy sources. The proposed system additionally produces both electrical energy and water, using hydrogen and water as storage units, with the latter being energy throughout its cycle as well as specifically in the desalination process (between 3 and 5 kWh are required to desalinate 1 m^3 of water).

The results obtained from the simulation and optimization studies show the feasibility of the system from both an economic and technical perspective. By way of comparison, a project considered for the island of El Hierro [41] obtained a cost of 88 M € to generate 11 MW [42], whereas a total of 1,052,891 € are required to generate 480 kW in El Risco, making the system proposed in the present paper approximately three times cheaper. In addition, the cost per MWh produced in the El Risco system is 107 €/MWh, while the generation of energy using fossil fuels (diesel) in the Canary Archipelago amounts to 200.45 €/MWh [43].

From an environmental point of view, the proposed system would mean an annual 664 t reduction in the emission of CO_2.

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